STRENGTHENING OF REINFORCED CONCRETE COLUMNS USING FRP FABRIC

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To my beloved family…

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ABSTRACT

In a number of cases, the compressive strength of reinforced concrete members have been found to be less than the design strength. Therefore, forcing the structural engineer to strengthen these members in order to cater for the dead, super-dead and superimposed loads to which these structural members are subjected to throughout their service life. In the case of under-strength columns, an efficient method of increasing the strength and ductility of these columns is by wrapping them with fibre-reinforced polymer (FRP) fabric. However, most previous studies on concrete short columns confined with FRP sheets were based on small-scale testing which did not take into consideration the size effect of these columns. In this study, 40 MPa concrete cylinders having height-to-width ratios (λ) of 4 and 8 are wrapped with CFRP sheets impregnated with epoxy and tested under uniaxial compression. Their ultimate failure loads are recorded and the performance of the wrapped cylinders is compared to the unwrapped control specimens in terms of the strength gain produced by the confining effects of the wraps.

ABSTRAK

Dalam beberapa kes, kekuatan mampatan struktur konkrit bertetulang didapati tidak mencapai kekuatan rekabentuk. Justeru itu, jurutera struktur terpaksa mencadangkan agar langkah-langkah penambahbaikan dilakukan terhadap struktur-struktur yang lemah ini untuk membolehkan struktur-struktur berkenaan terus dapat menanggung beban hidup dan beban mati yang dikenakan dengan selamat. Salah satu kaedah yang efisien untuk menguatkan struktur tiang konkrit yang lemah adalah dengan membalut tiang berkenaan dengan jaket FRP (serat polimer yang diperkuat). Dalam kajian ini, silinder konkrit gred 40 MPa dengan nisbah kelangsingan (λ) bersamaan 4 dan 8 dibalut dengan CFRP (serat karbon polimer yang diperkuat) dan diuji di bawah aplikasi daya mampatan. Beban puncak direkodkan serta kelakunan sampel silinder konkrit yang berbalut dibandingkan dengan sampel kawalan yang tidak dibalut daripada segi kesan penambahbaikan yang mungkin dihasilkan oleh balutan CFRP berkenaan.

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Ac	-	cross sectional area of concrete
Ag	-	gross cross-sectional area of concrete
Asc	-	cross-sectional area of longitudinal steel
Ast	-	cross-sectional area of longitudinal steel
D or d	-	diameter of circular concrete column
Ec	-	modulus of elasticity of concrete
E_{FRP}	-	modulus of elasticity of FRP
$f'c$	-	compressive strength of the unconfined concrete, measured by testing 150 mm x 300 mm cylinders according to ASTM C39
$f'cc$	-	strength of concrete due to the confinement effect of the FRP
$f'cc2:1$	-	confined concrete strength of a concrete specimen with L/D = 2
$f'co$	-	unconfined strength of concrete
fcu	-	characteristic strength of concrete
f_{FRP}	-	ultimate tensile strength of the FRP
fl	-	confinement pressure exerted by FRP
fy	-	characteristic strength of reinforcement
k	-	Stiffness = P/Δ
kg	-	gap factor
$k1$	-	confinement effectiveness coefficient
ks	-	shape factor
L	-	length of column
l_e	-	effective length of column
M	-	bending moment
Nu	-	ultimate axial load capacity of column
P	-	axial compressive load
Pn	-	axial load capacity of column

t or t_{FRP}	-	thickness of FRP or total thickness for multiple plies
γc	-	partial safety factor for concrete
γ_{frp}	-	partial factor for FRP tensile strength
γs	-	partial safety factor for steel reinforcement
Δ	-	axial deformation (shortening)
λ	-	column slenderness ratio (L/D)
νc	-	Poisson ratio of concrete
ψ_f	-	reduction factor for concrete

LIST OF ABBREVIATIONS

AFRP	Aramid Fibre Reinforced Polymer.
CFRP	Carbon Fibre Reinforced Polymer.
EBR	Externally Bonded Reinforcement.
FRP	Fibre Reinforced Polymer.
GFRP	Glass Fibre Reinforced Polymer.
HPC	High Performance Concrete
HSC	High Strength Concrete
RC	Reinforced Concrete.

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CHAPTER 1

INTRODUCTION

1.0 Introduction

In a number of cases, the structural strength of reinforced concrete members have been found to be less than the design strength, therefore, forcing the structural engineer to strengthen these members in order to cater the dead, super-dead and superimposed loads to which these structural members are subjected throughout their service life.

In the case of under-strength reinforced concrete columns, a few options are available to the structural engineer, among them:

(a) complete demolition and re-construction – this is the most radical alternative whereby strengthening of the member in question is either not feasible structurally or economically, or the structural engineer is unwilling to take any risks pertaining to the dubious strength of the said member.

For example, a 1000 mm diameter bored pile for a bridge foundation as shown in Figure 1.1 was found to be of under-strength concrete. The consulting engineer stipulated that the actual strength of the concrete has to be established by Schmidt Rebound Hammer Testing as shown in Figure 1.1. Core samples were also taken and tested as shown in Figure 1.2.

Figure 1.1: Schimdt Rebound Hammer Testing being carried out on the 1000 mm diameter bored pile.

Figure 1.2: Concrete cores taken from the 1000 mm diameter "under-strength" bored pile being tested.

The consulting engineer stated that if the in-situ concrete strength determined from rebound hammer testing and core tests was satisfactory, then the bored pile in question can be accepted as being of sound quality. On the contrary, if the concrete strength is determined to be lower than the design strength, then the bored pile should be abandoned and a replacement pile had to be constructed.

(b) enlargement – structurally this is the simplest and most obvious solution to strengthen under-strength columns as shown in Figure 1.3.

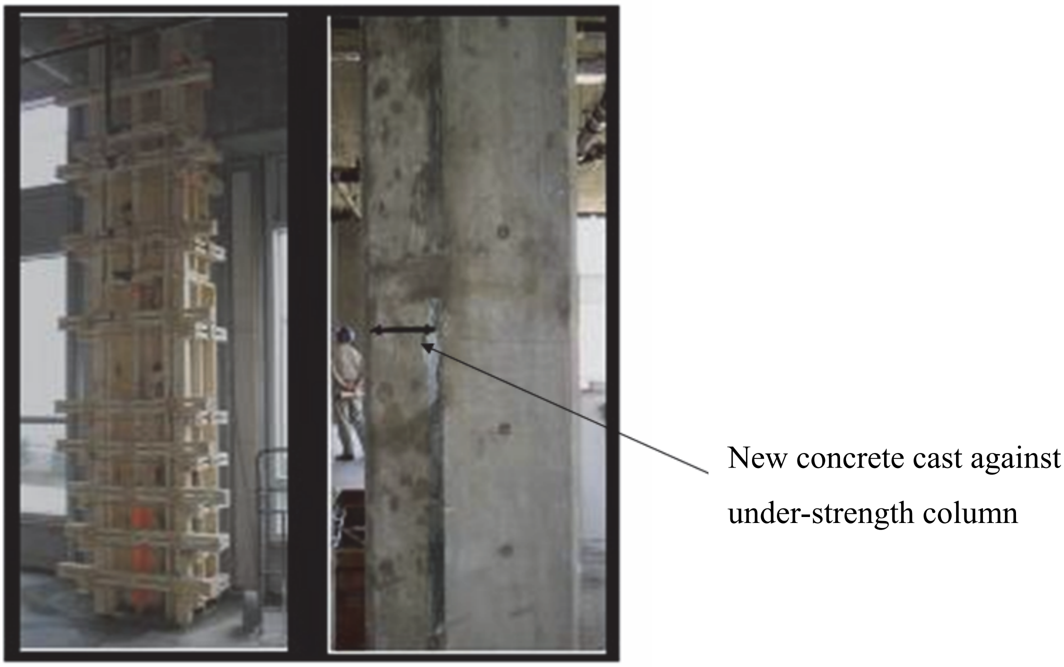

Figure 1.3: Strengthening of an RC column by enlarging its cross sectional area.

However, this method has a few drawbacks. First of all, expensive rentable floor area is lost when the dimensions of columns are enlarged. For example, when a 450 mm-square column is enlarged to 600 mm x 600 mm, approximately 2 square feet of floor space is lost. This leads to a loss in revenue from floor rental.

From project budgeting point of view, enlargement will incur additional material and labour costs.

(c) stress reduction – this can be achieved by the addition of extra columns, resulting in load distribution away from the under-strength column to the newly added columns as shown in Figure 1.4. Once again, this solution is both expensive and ruins the architectural functionality of the floor space.

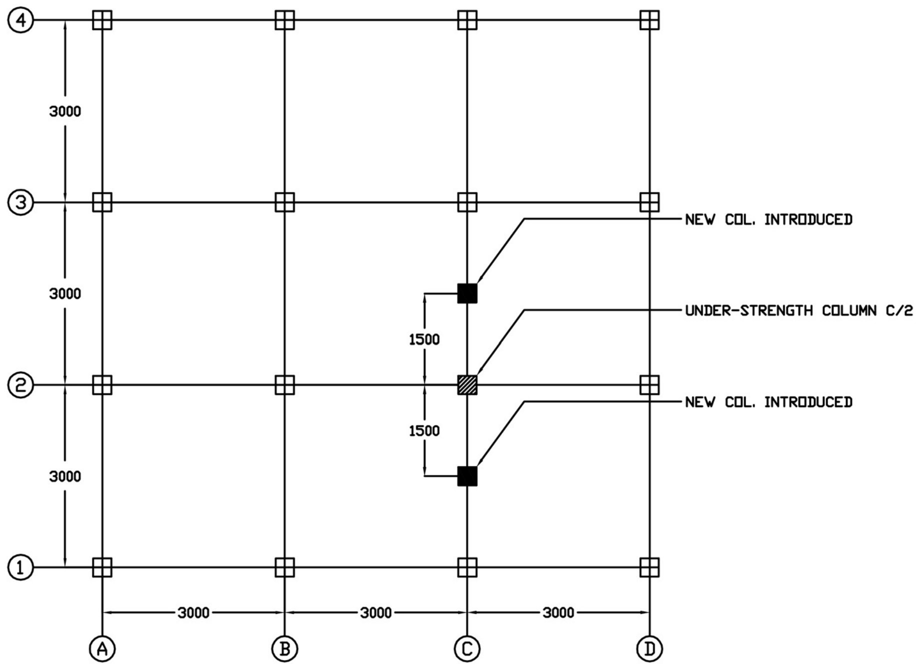

Figure 1.4: Two new columns are introduced in order to reduce the stresses experienced by the under-strength column C/2.

(d) installation of steel plates – this traditional method of strengthening reinforced concrete structural elements as shown in Figure 1.5 is now deemed both expensive and inefficient as the strength enhancement achieved per kilogramme of steel used is rather low.

Figure 1.5: Retrofitting of under-strength bridge column with a steel jacket.

This method also involves the lugging of thick steel plates to the construction site. Installation is difficult due to the weight of these plates which would have to be mechanically attached to the under-strength columns using bolts and nuts. Surface treatment of these plates is absolutely necessary for corrosion and fire protection, thus incurring further costs to the contractor.

(e) wrapping with FRP sheets – currently this method as shown in Figures 1.6 and 1.7 is gaining popularity as it is a clean and hassle-free method of strengthening structural concrete members. The confining effect of the FRP sheets enhances the compressive strength of the concrete.

Figure 1.6: Under-strength concrete column in a building wrapped with carbon fibre reinforced polymer (CFRP) sheets.

Figure 1.7: Retrofitting of a concrete bridge pier with glass fibre reinforced polymer (GFRP) sheets.

This study seeks to investigate the behaviour of circular concrete columns wrapped with CFRP fabric under the application of monotonic axial loading.

1.1 Objectives of the study

The objectives of the study are as follows:

i. To study the mode of failure of circular reinforced concrete columns wrapped with carbon fibre reinforced polymer (CFRP) sheet.

ii. To study the increase in axial load capacity of CFRP-wrapped columns as compared to unwrapped columns.

iii. To study the effects of column slenderness ratio, λ, on the axial strength gain of CFRP-wrapped columns.

1.2 Scope of the study

This study is restricted to circular column specimens wrapped with a single ply of CFRP sheet consisting of mid-strength carbon fibres under the application of purely compressive loading. As no eccentricity is considered, no bending moment is applied to the column specimens tested in the study. Normal concrete having a characteristic 28-day cube strength of 40 MPa is used. Neither high-strength (HSC) nor high-performance concrete (HPC) is considered. The slenderness ratios of the concrete specimens are restricted to values of $\lambda = 4$ and $\lambda = 8$.

1.3 Case study

It was required to increase the load capacity of a 300 mm by 450 mm rectangular RC column as shown in Figure 1.8 reinforced with 6 numbers of 20 mm diameter steel bars with the characteristic yield strength of steel is 400 N/mm^2. The compressive 28-day cube strength of the concrete [1] was 22.4 MPa giving an ultimate axial load carrying capacity of 1983 kN. By wrapping the column with four plies of BBR carbon fibre sheet CFS 240 – 300 gm/m^2, the ultimate load bearing capacity of the column was increased by 21.5% to 2409 kN.

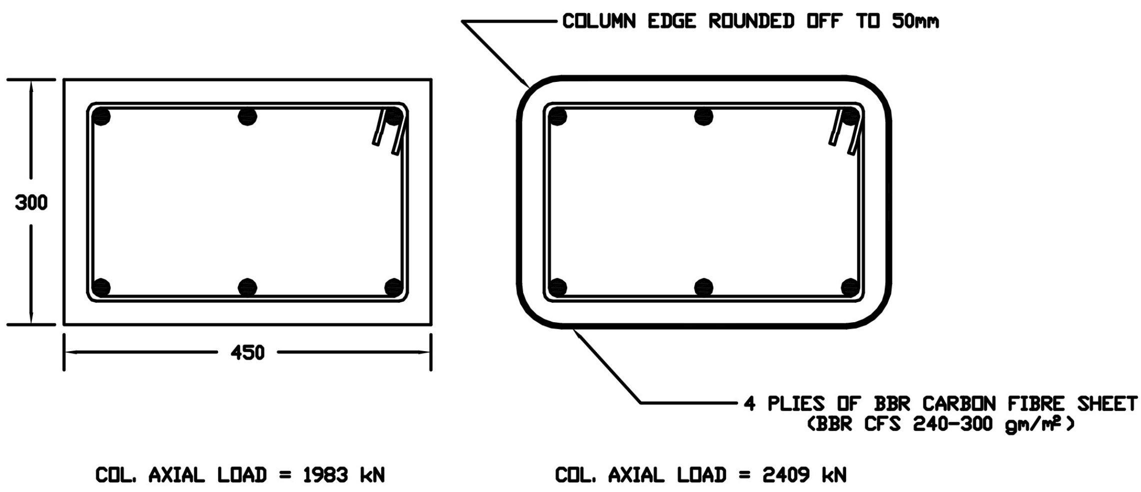

Figure 1.8: Axial load enhancement for a rectangular RC column achieved by CFRP wrapping.

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